What The Heck Is Inductance, Anyway?

A recent Gallup/CNN poll revealed that an astonishing 36% of the general population suffers from an inadequate understanding of magnetic inductance. That figure is even higher among physicists and engineers. Since the concept is central to understanding many aspects of the Main Injector, or of any accelerator, the basics will be presented here.

Inductance

Inductance can be thought of as resistance to a change in a magnetic field.

When current begins to flow in a conductor, a magnetic field begins to form around the conductor. The field forms in such a way to create a voltage that opposes the increasing current in the conductor. The polarity of the induced voltage is the opposite of the polarity of the voltage created by the changing current and the magnetic field. The induced voltage limits the rate at which current can be increased or decreased in a conductor.

As soon as the current reaches a stable value the magnetic field is consequently at a stable value, and the induced voltage vanishes.

The symbol used to represent inductance is, inexplicably, L. It is measured in units called henrys, probably after some guy named Henry. A henry is an unrealistically large unit for most everyday applications; the largest inductance in any Main Injector magnet is about 2 millihenrys. Line several hundred up in a big ring, however, and the total inductance will command some respect.

The inductive voltage across a system is given by:

$$V = L\frac{di}{dt}$$

where di/dt is the rate of change of the current, usually expressed as amps per second. The faster the current is changing, the greater the induced voltage.

The actual inductance, L, depends on the geometry of the magnet and is more complicated to compute. One factor is the number of turns. A straight conductor (one "turn") has the least inductance; inductance increases with the number of turns in a coil. That is the main reason why the coils in the Main Injector dipoles are large; if the same amount of current can be carried with fewer turns in the coil, the magnets can come to full strength faster because there is less inductance and a weaker opposing voltage. That means the Main Injector can be ramped more frequently, creating a higher stacking rate and ultimately higher luminosity for stores in the Tevatron. Wider is better.

The large dipoles in the Main Injector are in series. The copper bus emerges from one pair of magnets, passes behind the quadrupole, and re-enters the next pair, continuing in this fashion all the way around the ring. The inductance adds up with every magnet.

Pairing the "A" and "B" magnets, and the "C" and "D" magnets, distributes the inductance more evenly. The inductive voltage still opposes any change in current, but each power supply only sees about half of the opposing voltage that it would see otherwise.

The upper and lower bus are actually in series, but in the power supplies at MI-60 the upper bus turns around and becomes the lower bus, and the lower bus turns around and becomes the upper bus (Fig. 2-4). The inductive voltage is thus balanced in such a way that the voltages necessary for powering the ring are kept to a minimum.

Beneficial Aspects

There are beneficial aspects to inductance as well. Transformers use the inductance of the primary and secondary windings to step up or step down voltages. The fact that inductance resists sudden changes in current is employed when chokes are designed to smooth noisy power supply outputs. The inductance of the magnets in the tunnel blocks ripple from the power supplies so that resistors can attenuate it.

Resonant Systems

The inductance of every component has to be taken into account whenever designing an electrical system, but it is especially crucial in resonant systems. (Actually, every electrical system is a resonant system of some sort, but some devices are built specifically to exploit the phenomenon.) Inductance, along with capacitance and resistance, determines the frequency of the oscillations in a resonant system. Kickers, which transfer beam from one accelerator to another, and RF cavities, which accelerate the beam, are examples of resonant systems used in the Main Injector. More detail about kickers can be found in Chapter 7, and RF cavities will be described in the RF chapter.